Residential Energy Comparison: Built Green and LEED

ECOTOPE
CONSULTING
RESEARCH
DESIGN

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Introduction

The City of Seattle and King County have an interest in reducing the development impacts of new residential construction on regional energy and water resources, waste management, traffic, and greenhouse gas production. Two common green building rating systems purport to promote sustainable construction practices that reduce the environmental impact of new construction: the LEED rating systems of the U.S. Green Building Council, and the Built Green rating systems of the Master Builders Association. This study examines the benefits to the region which may result through the adoption of these rating systems into new building practices. Specifically, this report focuses on the energy impacts of these rating systems in single and multifamily construction in the local area (Seattle and King County).

To evaluate the impacts of the two rating systems, we analyzed five prototype buildings: a 1,850 ft^2 house, a 2,800 ft^2 house, a duplex consisting of two 1,400 ft^2 townhomes, a 60-unit mid-rise apartment building with 5-stories of wood framing over a concrete parking garage, and a 190-unit high-rise multifamily building with non-combustible, curtain wall construction. Each prototype building was considered with two types of heating systems: one based on natural gas and one electric-only. The prototypes were first evaluated built to the Washington State Energy Code (WSEC) typical construction standards. We then developed packages of energy efficiency improvements that would meet the requirements of the various levels of certification for the two Green Building rating systems. The mandatory energy efficiency levels dictated by the two programs are shown below for the various certification levels.

Table 1. Energy Savings Requirements for Various Program Levels.

Built Green	4-Star	5-Star
Single Family	Energy Star + low flow faucets	Energy Star + low flow faucets + Prescriptive envelope measures + lighting measures
Multifamily	15% modeled savings over WSEC	30% modeled savings over WSEC
LEED	**Silver**	**Gold**[1]
Single Family	Energy Star	Energy Star
Multifamily	14% modeled COST savings over ASHRAE 90.1-2004	14% modeled COST savings over ASHRAE 90.1-2004

This report is divided into an analysis of single family and townhome construction in the first half of the report and high-rise and mid-rise multifamily construction in the second half. The report is divided in this way because there are large differences in the building characteristics, rating systems, and energy savings results between single family and larger multifamily construction. A final section discusses the sensitivity of the results to assumptions about building glazing levels.

[1] Note that the LEED program offers one higher certification level: Platinum. This was not evaluated since there are no additional mandatory energy measures beyond the requirements for Silver and Gold.

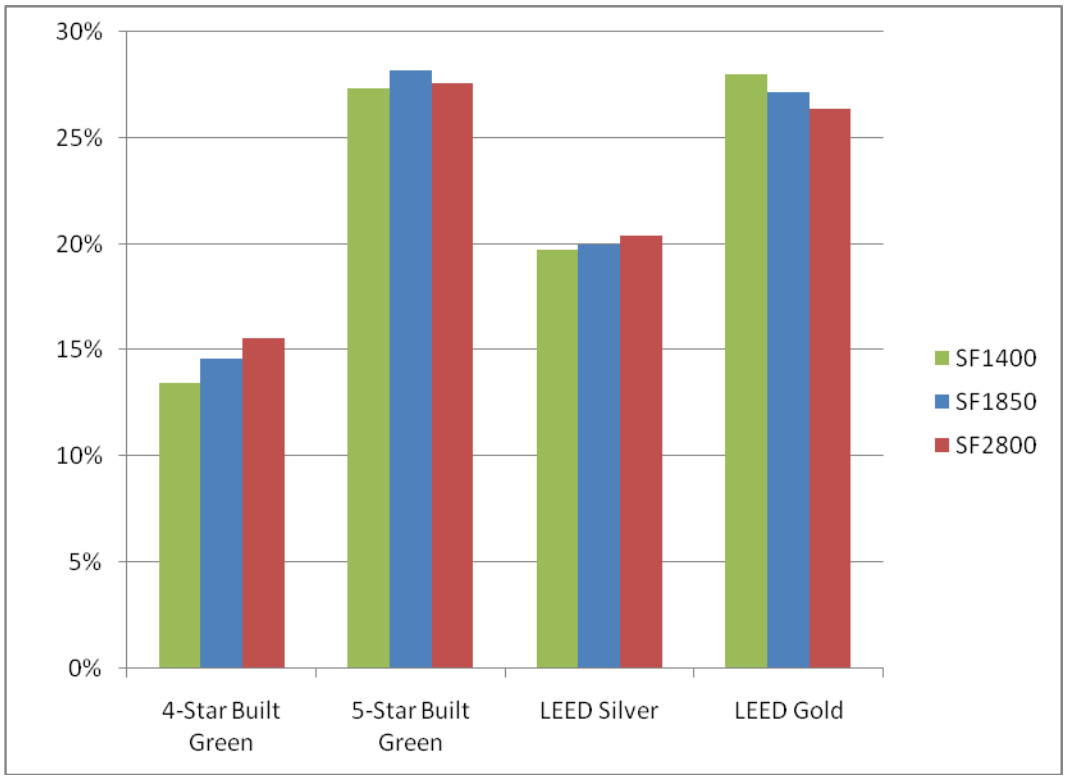
Single Family and Townhomes

Included in this section of the report are annual energy use calculations for three prototype dwellings: a 1850 ft^2 house, a 2800 ft^2 house, and a 1400 ft^2 townhome. The houses are standalone buildings, while the townhome is modeled as one of two, side-by-side units sharing a common wall. Each building is modeled with four different packages of measures aimed at reducing energy consumption in comparison to a WSEC base case. The four packages are: 4-Star Built Green, 5-Star Built Green, LEED Silver, and LEED Gold. The annual energy consumption is calculated for five categories: Appliances + Plugs, Lighting, Water Heating, Space Cooling, and Space Heating. Space cooling is only applicable to the electric path for Built Green 5-star and LEED Gold homes as they have been modeled with heat pumps[2]. Additionally, the buildings in the detailed breakdown are all assumed to have a 21% glazing to floor area ratio.

Primary Findings

The rating systems relevant to single family construction are the *Single Family Built Green* program and the *LEED for Homes* program. The figures below show the relative energy savings for the prototype single family gas-heated houses in terms of percent savings and total savings in comparison to the WSEC base case building. The 1,400 ft^2 building is a single townhome.

Figure 1. Percent Energy Savings Compared to 2006 WA State Energy Code (WSEC)



[2] The assumption was that 5-Star and Gold homes would not likely be sold with electric resistance heating. However, there is nothing in the programs which prohibit this.

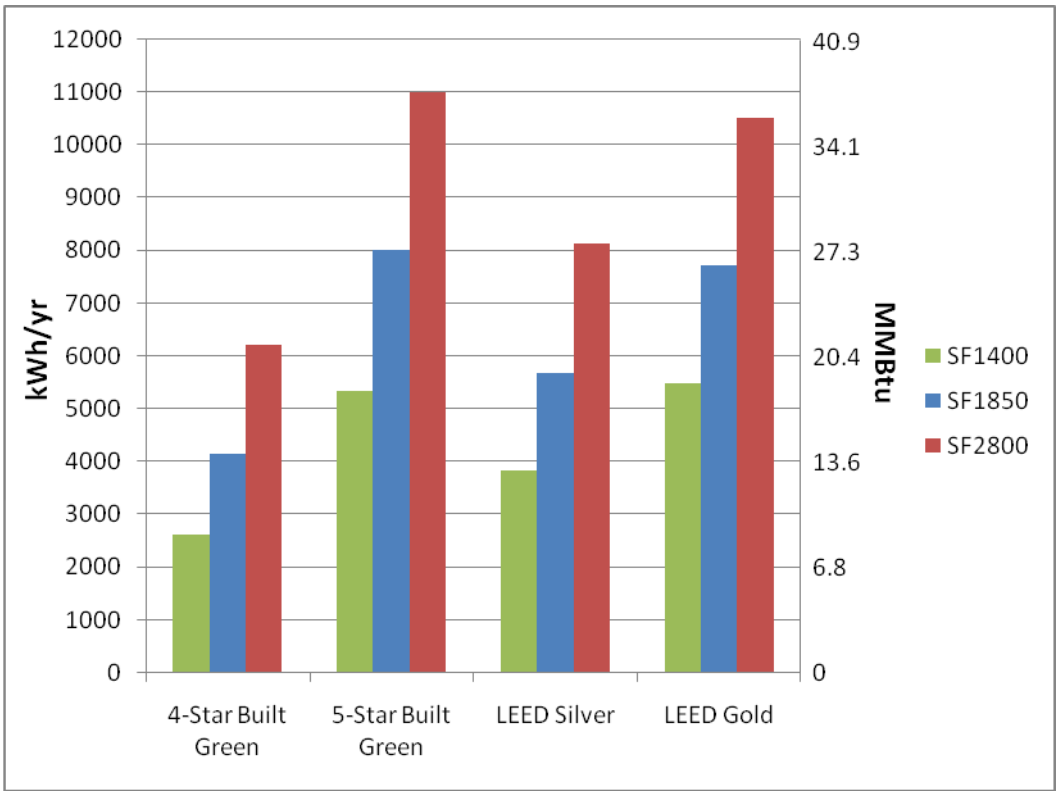
The programs appear to deliver real savings in most categories of energy use. The two programs also appear to deliver approximately the same level of savings. The 4-Star Built Green savings is 14% and LEED Silver is 18%. The 5-Star Built Green and LEED Gold are both 26%.

The majority of the energy efficiency measures delivering savings in the case of the 4-Star and LEED Silver cases are driven by the requirements of the EnergyStar program. Therefore a similar level of savings could be expected from application of the EnergyStar residential program. An advantage of the NW EnergyStar program is that it limits the glazing to floor area ratio to 21% which helps to control the heating load. The extent to which homes would exceed 21% glazing without the limit imposed by these programs is not accounted for in the baseline used to model the energy savings shown here.

Most of the energy savings in the 4-Star and Silver packages are not due to improvements in the building envelope relative to WA State Energy Code because these aren't required for EnergyStar. Rather they are due to improvements in heating equipment efficiency, appliances, water savings, and lighting measures. These programs are effectively reducing energy use in all areas except for miscellaneous electrical loads (MELs). MELs are a large fraction of energy use in residential buildings and are not addressed by any of these programs. Assumptions about MELs have a big impact on total anticipated energy use and space heating requirements. These become more important in smaller well-insulated homes. Future programs should seek a way to reduce these loads as well.

The most significant difference between the two rating systems in hot water savings is that Built Green has no incentive to install low-flow showerheads. By including this important measure in the Built Green program, 4-star Built Green energy savings could be improved with minimal effort.

Figure 2. Total Energy Savings[3] Compared to 2006 WSEC



The figure above shows the absolute energy savings for the various packages. Note that the total savings is strongly linked to the size of the home. This is because space conditioning and lighting energy are linked to home size. Larger homes use much more energy, so the potential savings are larger. An important impact to note is that both LEED and Built Green provide incentives to build smaller houses which, if effective, will have a very large impact on residential energy use.

Energy Modeling

The inputs used to create the different packages for the single family and townhome prototypes are summarized in Table 2. The parameters were developed based on mandatory program measures, measures that are common in the region, and measures that would yield points in the relative point system without significant cost or effort. Most of the measures applied at the 4-Star and Silver levels are mandated by the requirement to attain EnergyStar certification. The EnergyStar program mandates measures for the envelope, lighting, water heating, and appliances. EnergyStar has much stricter prescriptive requirements for electrically heated buildings than for buildings heated with fossil fuels. Additional mandatory measures were required for the 5-Star and Gold levels of certification.

[3] Gas usage was converted to effective kWh in order to have a common energy unit for comparison.

Table 2. Input Parameters for Single Family and Townhome Modeling

Component	Units	Base Case WSEC Compliant	4-Star Built Green	5-Star Built Green	LEED Silver	LEED Gold
Envelope						
Attic	U-Value	0.031	0.026[4]	0.026	0.026	0.026
Wall - Above Grade	U-Value	0.057	0.057	0.04[5]	0.057	0.057
Floors - Over Unheated	U-Value	0.029	0.029	0.029	0.029	0.029
Glazing - Vertical - Gas	U-Value	0.35	0.35	0.3	0.35	0.32
Glazing - Vertical - Elec	U-Value	0.35	0.3[6]	0.3	0.3	0.3
Glazing % of Floor Area	%	21%	21%	21%	21%	21%
Doors	R-Value	5	5	5	5	5
Ventilation						
Effective ACH Gas	ACH	0.35	0.35	0.3	0.3	0.3
Effective ACH Elec	ACH	0.35	0.19[7]	0.19	0.19	0.19
Heating + Cooling Equipment						
Gas-Fired	AFUE	80%	90%	90%	90%	92%
Elec - Heating	HSPF	3.413	3.413	8.5	3.413	8.6
Heat Pump - Cooling	SEER	NA	NA	13	NA	14
Water Heating						
Gas-Fired (50 gal) EF	EF	0.58	0.6	0.8[8]	0.6	0.8
Electric (75 gal)	EF	0.9	0.93	0.93	0.93	0.93
Distribution Losses	%	100%	105%[9]	105%	100%	100%
Low flow appliance/fixtures	%	100%	86.5%	86.5%	76%	70.7%
Lights/Appliance/Plug Loads						
Appliances	kWh/yr	1875	1520	1520	1520	1520
Lighting Density	W/ft^2	1.75	1.1	0.8	1.1	0.8
Plugs - Misc	kWh/yr	3200	3200	3200	3200	3200
Ducts and Controls						
Duct Location	Location	Crawlspace	Crawlspace	Crawlspace	Crawlspace	Crawlspace
Duct Insulation	R-Value	6	6	6	6	6
Duct Leakage Supply	% leakage	0.12	0.05	0.05	0.05	0.05
Duct Leakage Return	% leakage	0.10	0.03	0.03	0.03	0.03
Other Measures and Notes						
Tightness Testing		No Testing	Blower Door	Blower Door	Blower Door	Blower Door
Low-Flow Fixtures	GPM	2.5 shower 2.5 sinks	2.5 shower 1.0 sinks	2.5 shower 1.0 sinks	2 shower 1.0 sinks	1.75 shower 1.0 sinks
Lighting		Incand.	50% Energy Star	75% Energy Star	50% Energy Star	75% Energy Star
Appliances		Standard	Energy Star	Energy Star	Energy Star	Energy Star
Other Measures				R-5 wall foam, Adv. Frame		

[4] Built Green and LEED buildings assumed to use a raised heel truss w/ R-38 insulation. This is not a mandatory measure but one that is easily accomplished to gain points.
[5] R-26 walls are a prerequisite for 5-Star certification.
[6] U=0.3 windows and Heat recovery ventilation required by electric prescriptive path for EnergyStar.
[7] Northwest Energy Star program requires heat recovery ventilation for the electric heat prescriptive path w/ blower door tightness testing.
[8] Instantaneous gas water heaters assumed in 5-Star and Gold homes.
[9] Penalty taken for hot water recirculation loop installed for water conservation in Built Green homes.

Water Heating

Water heating energy was derived from regional residential submetered data and adjusted to account for current base water heater efficiencies.[10] Hot water consumption was assumed to be based on the National Energy Conservation Act standard 2.5 GPM baseline for all fixtures (showers, lavs, kitchen), and standard appliances. Savings were estimated based on low-flow fixtures and Energy Star appliances. The most significant difference between the two rating systems in hot water savings is that Built Green has no incentive to install low-flow showerheads.

The water heaters in the base case were assumed to be standard efficiency storage tank type water heaters. The most significant improvement to this in the gas heated case is to switch to an on-demand type instantaneous gas water heater for the 5-Star and Gold cases. This is not a required measure but one that is easily implemented for additional points and is becoming increasingly common in the region. There is no comparable measure in the electrically heated case.

Appliances

In this study, four major items make up the appliance category: refrigerator, dishwasher, clothes washer, and clothes dryer (electric). The base case appliances are chosen as typical units commonly in use in the Pacific Northwest. For all Built Green and LEED homes, typical Energy Star appliances are used.[11]

Miscellaneous Electric Loads

One constant across all the models (base case, Built Green, and LEED) in the study are plug loads, otherwise known as miscellaneous electric loads (MELs). These comprise all electricity consuming devices found in a house excluding the HVAC system, lighting, hot water, and the big four appliances mentioned elsewhere. A typical home could easily have over a hundred devices in use over the course of a year. The highest energy consuming devices are items that are in use continuously or most days such as televisions, cable boxes, VCRs or DVD players, component stereo systems, computers, microwaves, coffee makers, and secondary refrigerators.[12]

[10] Carolyn Roos and David Baylon. *Non-Space Heating Electrical Consumption in Manufactured Homes: Residential Construction Demonstration Project Cycle II*. October 1992, Ecotope. Prepared for Bonneville Power Administration.

[11] Energy use for Energy Star and standard appliances was derived from a spreadsheet developed for program evaluations by Tom Eckman for the Oregon Energy Trust.

[12] Hendron, Robert. 2007. *Building America Research Benchmark Definition, Updated December 20, 2007*. NREL/TP-550-42662. Golden, Colorado: National Renewal Energy Laboratory.

The actual total MEL number from house to house will vary dramatically with lifestyle. To a lesser degree it will depend on the number of occupants and on floor area. Importantly for this study, neither Built Green nor LEED make an attempt to regulate MELs. Therefore, there is no reason to believe the plug load will vary across any of the energy efficiency paths considered. The number used in the study is 3,200 kWh/yr which has been suggested by others as an average value.[13]

Lighting

The energy used for lighting was calculated by the simple formula:

Annual lighting energy use (kWh) = LPD x CFA x Hours

Where LPD (W/ft^2) is lighting power density, CFA (ft^2) is conditioned floor area, and Hours (hrs/yr) the average number of hours in a year the lights are on. The standard value used for Hours is 730 hrs/yr which is an average of 2 hours per day for every light in the house.[14] The LPD is given in Table 1. Energy Star lighting fixtures/lamps are mandated by the Built Green and LEED programs. The most significant impact on lighting energy is to replace incandescent fixtures with fluorescent fixtures. Both single family programs require installing a certain fraction of Energy Star compliant lighting fixtures. This is an area that could yield additional energy savings as incandescent lights are eliminated completely.

Space Heating and Cooling Equipment

All of the gas heated homes were assumed to use gas furnaces installed in the garage with ducts located in the crawlspace. This is not the most efficient setup, but it is the easiest and most common in the region. Incremental improvement to the efficiency of the gas furnaces is made in the program buildings. Additional improvement could be made by moving the furnace and ducts into the heated envelope of the building.

The electrically heated buildings are assumed to have zonal electric heat except for the 5-Star and Gold buildings which were assumed to have heat pumps. This assumption skews the savings estimates for these prototypes as this has a very large impact on predicted savings. It should be noted that this measure is not required by either program so the savings related to this measure are not reliably achieved. The 5-star and Gold homes were modeled in this way based on an assumption that these would be higher cost homes where air conditioning would be expected by the market.

Ducts are assumed to be insulated to minimum code levels in all cases. Ducts are sealed and tested in the program buildings and assumed to be marginally sealed in the code base building.

[13] Hendron, Robert. 2006. *Development of an Energy-Savings Calculation Methodology for Residential Miscellaneous Electric Loads*. NREL/CP-550-39551. August 2006. Golden, Colorado: National Renewal Energy Laboratory

[14] NW Power and Conservation Council. Regional Technical Forum lighting savings calculators. http://www.nwcouncil.org/energy/rtf/about.htm

Cooling is not installed in any of the prototype buildings. However it is assumed to be used in the buildings where heat pumps were installed. This increased energy use for air conditioning is more than offset by the reduced heating energy required with a heat pump.

The code base case building is assumed to have combined ventilation and infiltration equal to 0.35 air changes per hour (ACH). This is assumed to correlate with a blower door tightness test of 7ACH @ 50Pa. The various program levels require blower door tightness tests that correlate to higher levels of air tightness. Furthermore, the NW EnergyStar program requires heat recovery ventilators in electrically heated homes. Therefore the effective ventilation rate for modeling was adjusted to take into account the higher level of air tightness and the heat recovery efficiency.

SEEM (Simple Energy and Enthalpy Model)

The single family prototype building space heating and cooling loads were modeled with SEEM, an energy use simulation model developed at Ecotope. The SEEM program was designed to model small scale residential building energy use. The program consists of an hourly thermal simulation and an hourly moisture (humidity) simulation that interacts with duct, equipment, and weather parameters to calculate the energy requirements of the building. It uses algorithms consistent with current ASHRAE, ARI, and ISO calculation standards. Additionally, SEEM has been extensively used in the Northwest to estimate conservation measure savings for regional energy utility policy planners.[15]

To create a simulation, SEEM takes a number of input parameters including those for occupancy, equipment, ducts, envelope, foundation, and infiltration. SEEM generates a number of outputs including building UA, heating load, heating equipment input, cooling load, and cooling equipment input. A sample of the SEEM hourly output calculations used in this report is included in Appendix A.

Building Parameters

The buildings in the study were conceived of as relatively simple 2x6 wood framed boxes. The single family detached houses are both two level buildings built over a crawlspace with a ground floor garage. The second level sits atop a garage and has more conditioned floor area than the first. For the townhome, a two unit building was conceived and one unit from the building was modeled. The building is three levels with the ground level being unconditioned parking space. The townhome unit benefits from reduced heat loss due to the common wall in the building. All of the prototypes were modeled with 21% glazing area to floor area ratio with the glazing equally divided in the 4 cardinal directions. The building dimensions are specified in Table 2.

[15] Used by NW Energy Star program, Idaho Power, Puget Sound Energy, Energy Trust of Oregon, and to predict savings for the 2010 NW Power Plan for the NW Power and Conservation Council.

Table 3. Single Family and Townhome Building Parameters

	SF Detached		SF Town House
	1850 ft^2	2800 ft^2	1400 ft^2
Width	20′	24′	18.75′
Length	52′	70′	37.5′
Garage Dimensions	12′ x 20′	24′ x 24′	18.75′ x 37.5′
Ceiling Height	8′	8′	8′
Level 1 Conditioned Floor Area (CFA)	805 ft^2	1045 ft^2	700 ft^2
Level 2 Conditioned Floor Area (CFA)	1112 ft^2	1688 ft^2	700 ft^2
Occupants	3	3	2.5

Internal Gains: Energy and Moisture

To accurately model both heating and cooling loads, the internal heat and moisture gains must be considered. The internal heat gains were determined based on a function of lighting, appliances, and occupancy (3 people for SF1850 and SF2800, and 2.5 people for the townhouse). In practice this means, as more energy efficient appliances and lighting are used, the internal heating gains of the building decreases, thus requiring a larger input from the heating system. Conversely, during days when cooling is required, the input to the cooling system will be less.

Results

The following pages graphically present the annual energy demands of the prototype houses with the various packages of measures described in Table 2. Appendix B contains the data used to derive the graphs. Natural gas energy use has been converted to equivalent kWh of electrical energy so that direct comparisons can be made on the basis of energy. Note that this is energy consumed on the site, so the source of the electrical generation is not taken into account by this comparison. This leads to gas heated buildings using more energy due to the inefficiencies associated with combustion, and does not penalize the electrical grid for inefficiencies associated with generation and transmission.

Following the energy comparisons are tables showing the CO_2 impacts of the various prototypes and measure packages. To calculate the CO_2 emissions, we assume 0.6 metric tons per MWH for electric use[16] and 11.7 lbs/therm for gas use.[17] Here, the varying contributions of electrical and gas usage to atmospheric CO_2 become evident. This comparison takes into consideration the source of the electrical energy and inefficiencies associated with generation and transmission. The amount of CO_2 per kWh is based on an assumption that some percentage of all new electrical generation in the region must come from burning natural gas and coal in combustion turbines.

[16] Assumed by the City of Seattle as the CO2 impact of their marginal new electrical generation.
[17] US Energy Information Administration. http://www.eia.doe.gov/oiaf/1605/coefficients.html

Figure 3. Annual Site[18] Energy Use – 1,850 ft^2 Prototype

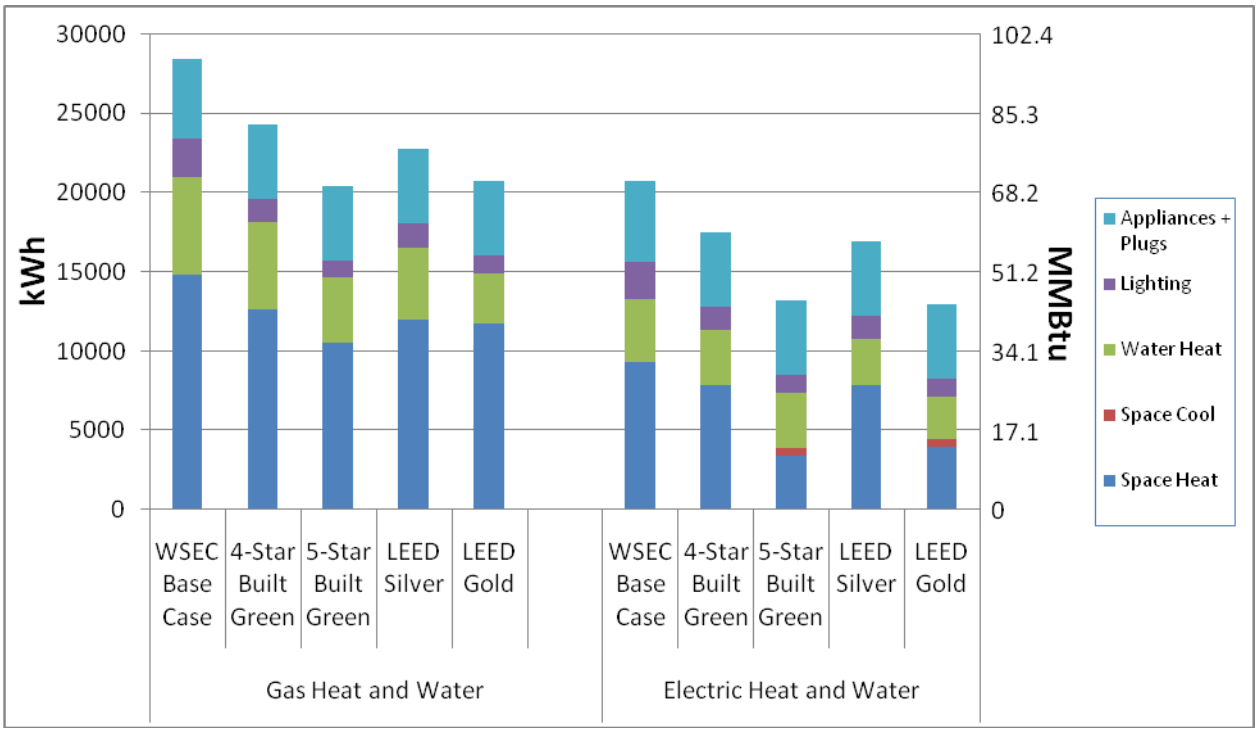
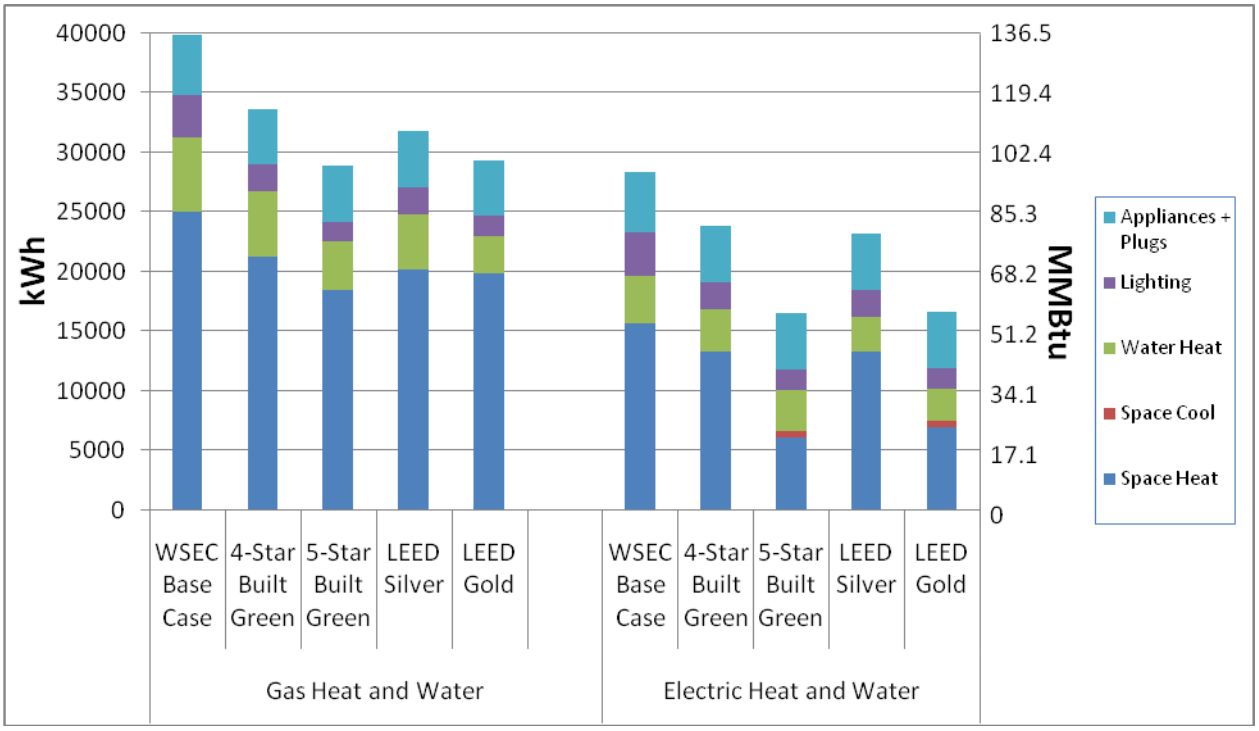


Figure 4. Annual Site Energy Use – 2,800 ft^2 Prototype



[18] Site use energy: Natural gas + electricity used by the home converted to common energy units.

Figure 5. Annual Site Energy Use – 1,400 ft^2 Townhome

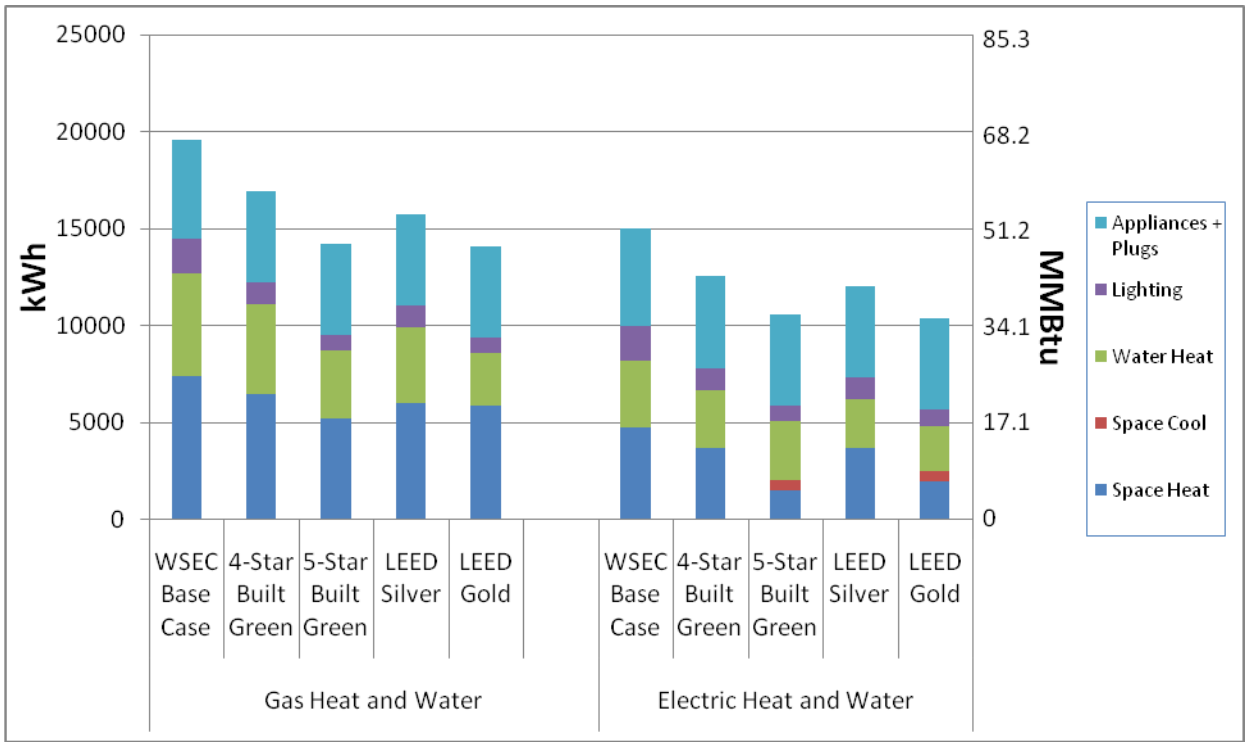
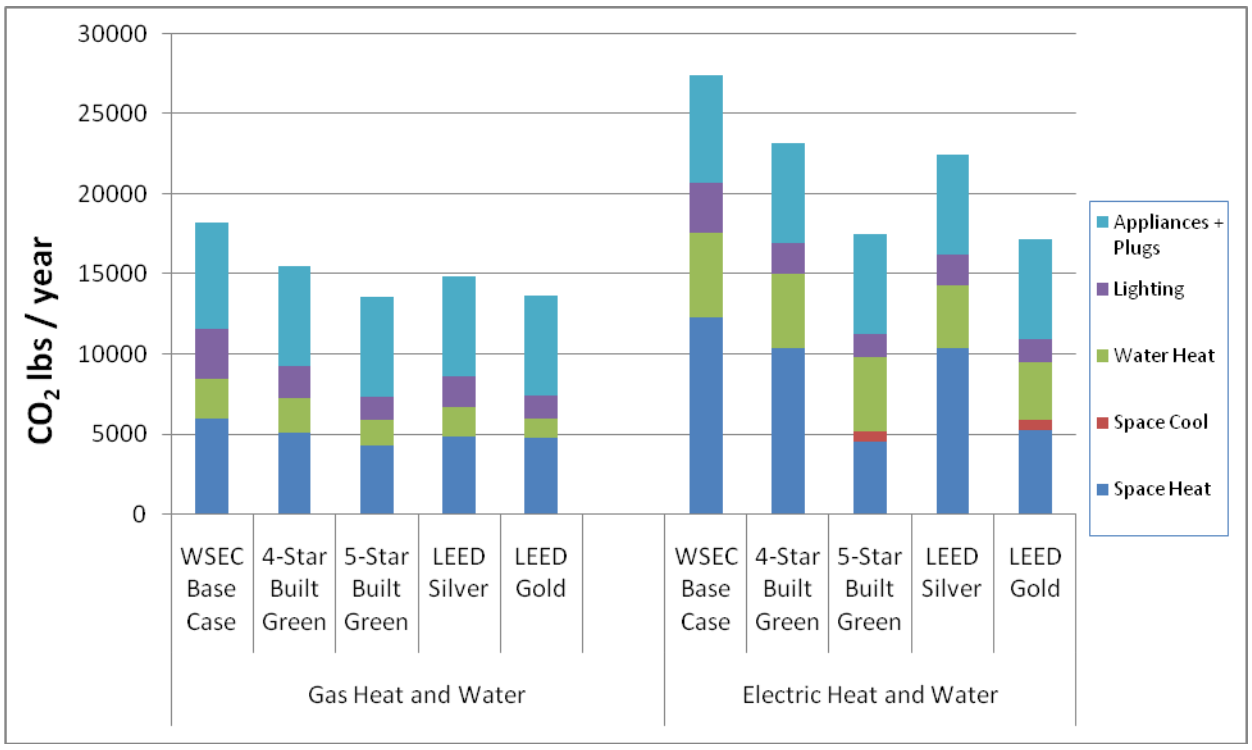


Figure 6. Source Energy CO_2 Emissions[19] – 1,850 ft^2



[19] CO2 emission rates are based on source energy assumptions which account for emissions associated with electricity generation and distribution.

Figure 7. Source Energy CO_2 Emissions – 2,800 ft^2

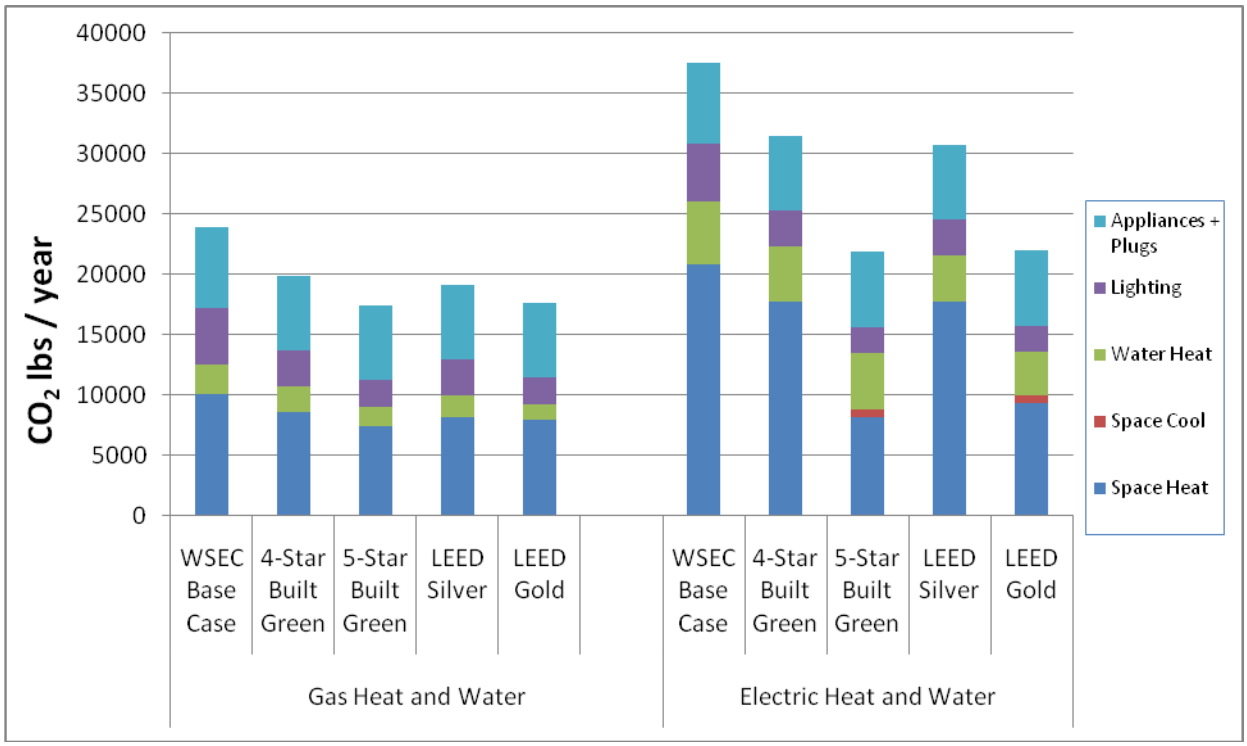
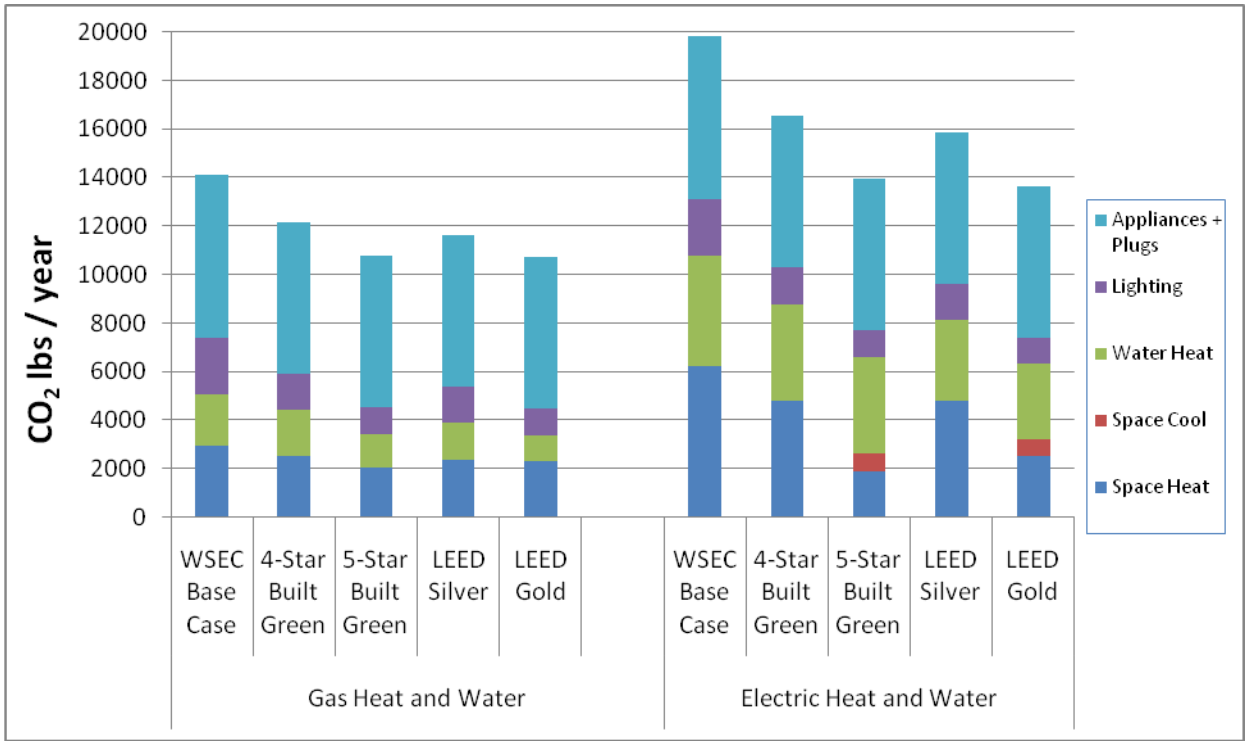


Figure 8. Source Energy CO_2 Emissions – One 1,400 ft^2 Townhome



Analysis

The programs appear to deliver real savings in most categories of energy use other than the MELs which are unregulated. The programs also appear to deliver approximately the same levels of savings; about 15% for 4-Star or Silver and 25% for 5-Star or Gold.

The 5-Star and Gold programs differ in their energy savings measures but produce remarkably similar savings. 5-Star buildings use better insulation on the building thus reducing space conditioning loads, but realize less savings from water heating in comparison with the Gold path. For instance, 5-Star buildings have a layer of exterior R-5 foam insulation on all walls compared with no additional insulation for Gold. In contrast, the Built Green buildings use 2.5 GPM shower heads whereas LEED Gold uses 1.75 GPM reducing the water heating load.

The energy savings measures for the 4-Star and Silver programs are nearly identical. The only significant differences occur between low-flow showers and air tightness measures Built Green does not provide any incentive for low flow showers, and LEED requires blower door testing to 3.0 ACH for houses heating with gas.

The relatively large savings shown for the 5-Star and Gold rated buildings in the electrically heated path are primarily associated with an assumed switch from electric resistance heat to heat pumps. This may or may not be a realistic assumption as heat pumps are not required by either program[20]. The switch to a heat pump improves the savings to 30% for both 5-Star and Gold. Without a high-performance heat pump, the savings would be similar to the gas path, an approximate 25% reduction in overall energy use.

[20] The large savings for the heat pump cases are also in comparison to an electrically heated code building. This may not be a fair comparison since a heat pump could also be present in the code building.

Mid and High-Rise Multifamily Buildings

This section presents the results of our multifamily building analysis. These buildings fall into a different category for both the Built Green and the LEED programs. The Built Green multifamily program has just been made available and, at the time of the writing of this report, has yet to be applied to any actual buildings. There is no LEED program designed specifically for multifamily buildings, so these buildings fall under the commercial building program LEED NC which was initially developed for office buildings. These programs do not produce results that are as consistent or reliable as the single family programs. The main reason this is true is that the single family programs are largely prescriptive in nature, requiring specific energy conservation measures to be applied. The multifamily programs rely on energy modeling, the results from which can vary widely depending on the model used, the input assumptions, and the experience of the modeler. Multifamily buildings also cover a wider range of building types from simple wood frame construction with electric heat to high rise steel and concrete curtain wall buildings with central heating and cooling systems. Another common complication with multifamily buildings is mixed use buildings including commercial spaces on the first floor. This study has not attempted to address mixed use buildings.

LEED NC and Built Green Multifamily treat energy points rather differently. The Built Green program has specific prerequisites for 4 and 5 Star ratings requiring a minimum of 15% and 30% energy savings (respectively) in comparison to the WSEC. The LEED program requires a minimum of 2 points for energy savings (EA credit 1). This requires a minimum savings of 14% in energy ***cost*** for any certification level in comparison to the ASHRAE 90.1-2004 standard. This standard falls far short of the WSEC for multifamily buildings. Furthermore, the standard requires modeling to compare to specific base case mechanical systems which provide a large benefit for certain mechanical system selections while penalizing others. The ASHRAE 90.1 standard regulates only insulation, HVAC efficiencies, commercial lighting, water heating, and other miscellaneous HVAC loads. It does not regulate appliances or residential lighting, so savings in this area are not applicable to the credit totals.

Primary Findings

The rating systems relevant to the larger multifamily buildings are Built Green Multifamily and LEED NC. The savings associated with the LEED and Built Green programs are much less predictable and robust in the multifamily sector in comparison to the single family sector. Savings vary widely depending on the program (LEED vs. Built Green), the average size of the units, the type of construction, the glazing fraction, the type of mechanical system, and the experience of the energy modeler.

The LEED NC program was written primarily for commercial buildings with offices as the initial target sector. At this point there is no prescriptive path for achieving energy points in LEED for a multifamily building so a commercial building modeling program must be used. Because of this the energy savings are calculated from a commercial building base case defined by the ASHRAE 90.1 standard.[21] LEED requires a minimum of 14% savings in *energy cost* in comparison to

[21] ANSI/ASHRAE/IESNA Standard 90.1-2004. Energy Standard for Buildings Except Low-Rise Residential Buildings.

Standard 90.1. This standard is not a good base for multifamily buildings due to lax envelope insulation requirements, poor guidelines regarding baseline domestic hot water (DHW) usage, residential lighting, appliances, or MELs, and mechanical system assumptions based on commercial buildings.

The envelope requirements of 90.1 are far below what is required by Washington State Energy Code. For example, glazing is assumed to have a U-Value of 0.62 in the ASHRAE base case compared to 0.35 allowed by the WSEC. This gives a large point advantage to buildings with higher levels of glazing. Unit size also has a large impact on modeled energy savings. Larger units have higher heat loss rates and lower relative internal gains so the savings associated with envelope and heating system improvements are larger. For example, the gas heated high rise prototype has relatively large units (1232 ft^2) and a relatively high level of glazing (21%). Simply building this prototype to the minimum requirements of the WSEC results in a 12% predicted savings over the ASHRAE 90.1 base case. To achieve the minimum 14% savings for LEED Silver or Gold certification requires only the addition of low-flow showerheads. Many high rise multifamily buildings are being built in downtown Seattle with even larger units and 35% or higher glazing fractions which makes this effect even more noticeable. With some of these buildings it will be possible to achieve the required two energy credits simply by meeting WSEC requirements. On the other hand, smaller units with low levels of glazing have a much harder time earning energy points. This is because as the units get smaller and better insulated the heating energy becomes very small and internal gains begin to dominate. This makes it hard to save a large fraction of the energy by improving the envelope and HVAC system efficiencies.

ASHRAE 90.1 does not regulate appliances or residential lighting, so there are no easy ways to get credit for appliance and lighting measures under this standard. Therefore the LEED program provides no direct incentive to install energy efficient lighting or appliances. This effectively limits the areas of modeled savings potential to HVAC and domestic hot water and the LEED program can be expected to yield lower savings than Built Green.

The other area that has a large impact on modeled energy savings is the choice of heating systems. ASHRAE 90.1 defines the base case heating system differently depending on whether or not the building is heated with electricity or fossil fuels. The ASHRAE base case mechanical system for electrically heated buildings includes heat pumps. This means that if your multifamily building is heated with electric resistance you have to compare against a building with heat pumps. This makes it very difficult to demonstrate a high level of energy savings. Furthermore, the ASHRAE modeling guidelines require the building to be modeled with air conditioning whether or not any air conditioning equipment exists. Residential equipment is difficult to model in many commercial modeling programs. All of these effects mean that the modeled energy use for multifamily buildings rarely relates well to actual metered data.

Inexperienced (or even experienced) modelers can produce widely ranging savings estimates for the same building depending on input assumptions to the model. This cannot be over-emphasized. Possibilities for gaming the models abound, but even without intentional gaming,

the savings estimates from sloppy or inaccurate modeling can be hugely over estimated[22]. For example, larger baseline assumptions on DHW usage can yield very large savings estimates for low-flow plumbing fixtures. Under estimating internal gains from lights, appliances, and MELs will drive up predicted heating loads and energy savings. Many default values and schedules built into the models are hard to find and not appropriate for multifamily buildings. Therefore savings estimates for multifamily buildings from ASHRAE 90.1 modeling will not be likely to yield reliable results.

The Built Green program avoids some of the problems associated with the ASHRAE 90.1 base case by using a WSEC base case. However, the program provides no guidelines whatsoever regarding how savings are to be modeled. The prerequisite for achieving a 4-Star Built Green rating is, "Building modeled to have 15% better performance than energy code".[23] This leaves it wide open to a range of programs and modeling conventions that could yield poor results. With no clearly defined base case the modeler is free to set an unrealistic base case building so that the system can be easily gamed. On the other hand it allows a conscientious modeler a more direct way to account for actual mechanical systems, appliance, hot water, and lighting measures.

Prescriptive measure requirements such as are relied upon in the single family programs would be a better way to achieve reliable energy savings compared to relying on energy modeling estimates. If modeling estimates are to be used then the models should be constrained to specified inputs regarding lighting energy, DHW usage, and internal loads to improve the overall energy estimates.

The various effects mentioned above mean that large, heavily glazed, gas heated buildings can relatively easily achieve 4 or more energy points in LEED. However, small lightly glazed electrically heated buildings will be challenged to even meet the 2-point prerequisite. Most buildings will be able to meet the 15% energy savings prerequisite for Built Green 4-Star, but very few will be able to achieve the 30% savings target for 5-Star certification without applying measures that are rarely applied in the current multifamily building market in this region. These measures include triple glazing, wastewater heat recovery, and heat recovery ventilation. This makes it unlikely that these levels of certification will be attained by a large fraction of the new multifamily buildings.

One significant area of energy use in these buildings that has largely been overlooked by the codes, conservation programs, and by the building community is the corridor ventilation system. Our modeling indicates that, depending on how it is configured, this system can easily use as much heating energy as all of the apartments in the building. The maximum flow rate for these systems is not regulated by any code nor are the control methods. Most of these systems continuously pressurize the corridors with 100% tempered outside air. This is an area that could yield large energy savings through better design and conservation strategies.

The following graphs show the energy savings of the prototype buildings compared to the WSEC for the various packages of measures. Note that the Built Green prototypes achieve the target

[22] Interestingly modeling errors tend to disproportionately overestimate savings since there is less incentive to find and fix errors that underestimate savings.
[23] Built Green Project Checklist: Multifamily 2008 Extended Pilot Master.

savings by definition since the 15% and 30% savings targets are prerequisites for 4 and 5-Star certification levels. On the other hand the LEED buildings are only required to attain 14% savings over ASHRAE 90.1 for any level of certification, so for the mid-rise prototype and the high rise electric prototype the Silver and Gold buildings provide the same level of savings since gaining further points would require expensive uncommon measures to be applied. Only in the high rise gas heated case do we see relatively easy measures available to increase savings to achieve 4-points for the Gold building.

Figure 9. Energy Savings Compared to 2006 WA State Energy Code (Gas Path)

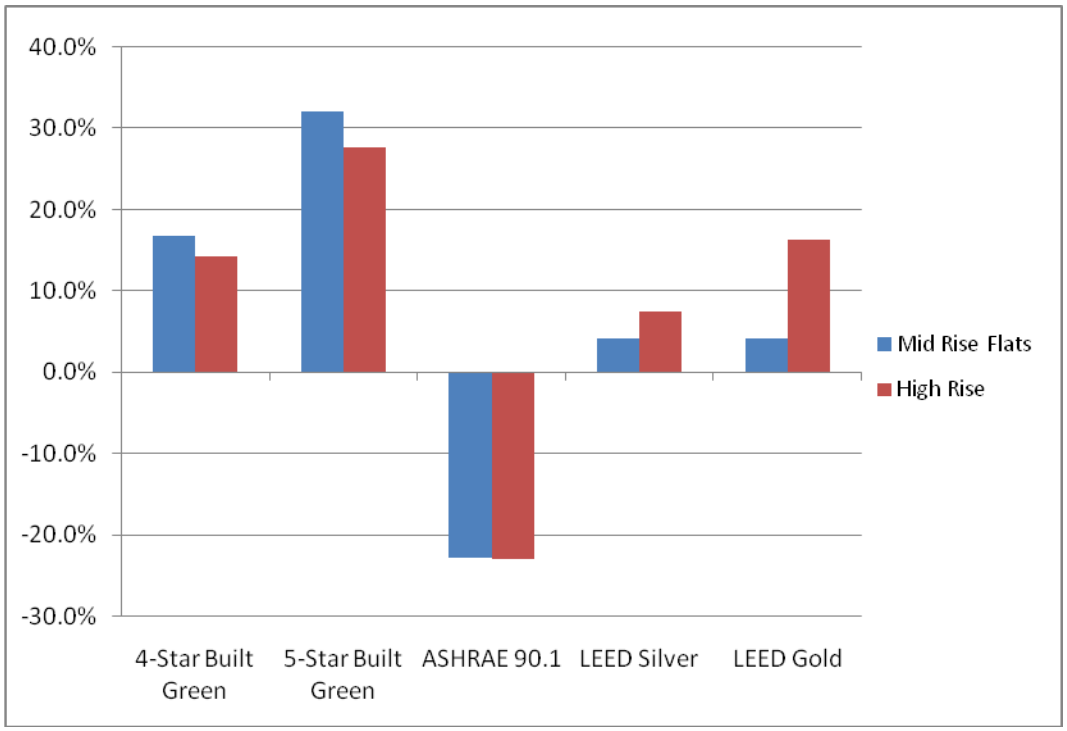
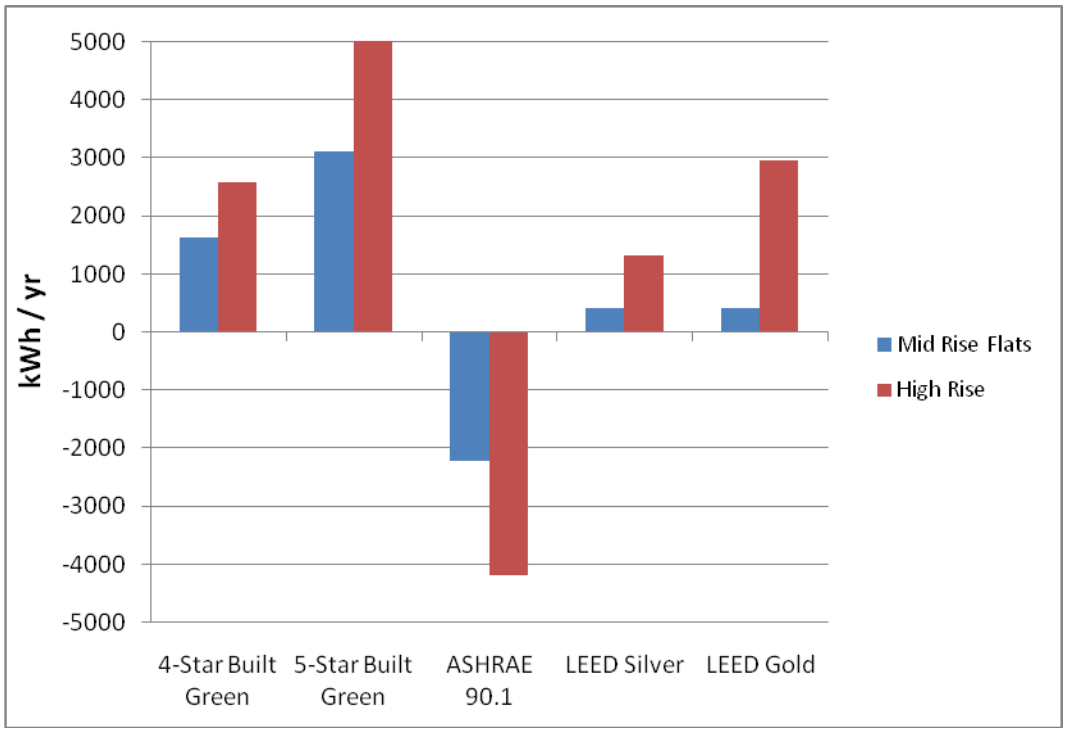


Figure 10. Total Energy Savings[24] Compared to 2006 WSEC (Gas Path)



Energy Modeling

The *eQuest* energy modeling program was used to model energy use in the multifamily sector.[25] The multifamily sector was characterized by two prototypes; a mid-rise wood-framed building and a high-rise curtain wall building. The energy conservation measures applied to the prototype buildings are shown in the Table 4 in the Results section below. The following sub-sections describe how the prototype buildings were developed and modeled to predict annual energy use.

Mechanical Systems

The modeled mechanical systems for the multifamily buildings were as follows:

- Gas Heating: Central gas boiler with 4-pipe fan coils in high rise building and hydronic radiators in the mid-rise building.
- Electric heating: 2-pipe fan coil with electric heat in high rise and electric baseboards in the mid rise. Heat pumps were added to the top floor in some cases to achieve point thresholds.
- Gas water heat: Central water heating system.
- Electric water heat: Tanks in the units.

[24] Gas usage was converted to effective kWh in order to have a common unit of comparison.
[25] eQuest (Quick Energy Simulation Tool) is based on the DOE2.2 program developed by LBL.

- Air-conditioning: central chiller with fan coils in high rise, no air conditioning in mid rise.
- Pumping: Variable Frequency Drive pumping (VFD).
- Corridor Pressurization: 80% efficient gas make-up air unit.

For the ASHRAE 90.1 base case the modeling protocol requires modeling a PTAC for cooling with an EER of 8.4[26], an 80% gas boiler for the gas heated buildings, and Packaged Terminal Heat Pumps (PTHPs) with a COP of 2.73 for heating in the electric case.

Envelope

The envelope insulation levels assumed for the base case buildings is shown below:

Table 4. Base Case Envelope Insulation Levels

Base Case Envelope	Units	2006 WSEC	AHSRAE 90.1-2004
Flat Roof	R-Value (U)	30 (0.034)	19 (0.065)
Wall - Above Grade	R-Value (U)	21 (0.057)	19 Metal (0.113)
Floors - Over Unheated	R-Value (U)	30 (0.029)	11 (0.087)
Glazing - Vertical	U-Val./SHGC	0.4/0.36	0.62/0.39

Wall insulation measures beyond the R-21 base case for code are very rare in the region for multifamily buildings. Waterproofing consultants mandated by relatively new insurance laws have been very skeptical about allowing exterior foam insulation due to concerns about moisture problems. In the high rise construction with metal studs and PT slabs extending to the perimeter it can be challenging to simply meet the requirements of the energy code for wall performance. Ceiling and floor insulation can be increased beyond code minimum, but with multi-story buildings this is a very small effect. This leaves glazing performance as the only real envelope measure available. Increments in glazing performance were added as needed to achieve the target savings. The increment to triple glazing can be relatively affordable in the case of vinyl windows in punched openings such as in the mid-rise prototype and this measure is recently becoming more common. In the high rise curtain wall case, however, there are extremely few, if any, examples in the region.

Appliances, Lighting, MELs

In this study, four major items make up the appliance category: refrigerator, dishwasher, clothes washer, and clothes dryer (electric). The base case appliances are chosen as typical units commonly in use in the Pacific Northwest. For the Built Green case typical Energy Star appliances are used. Appliance loads are unregulated by 90.1 so there is no incentive under the LEED program to install efficient appliances.

Likewise lighting inside the residential units is unregulated by LEED so there is no incentive to install fluorescent lighting fixtures. On the other hand under the Built Green program lighting is

[26] Even if cooling is not present in the proposed building it must be modeled for 90.1 and is assumed to have the same efficiency as the base case.

an important measure to get the buildings to the 15% and 30% thresholds. As in the single family prototypes, base case lighting is assumed to be 1.75W/ft^2 and on average used 2 hours per day.

Plug loads (MELs) are not regulated by either program. It was assumed to be slightly lower in multifamily than in single family buildings since occupancy is typically lower and there is less room for miscellaneous electrical appliances. MELs were assumed to amount to 2500KWH/yr.

Results

The following pages graphically present the annual energy demands of the prototype buildings with the various packages of measures described in the tables above. The most striking characteristic here is that the Built Green program is targeted to achieve a set level of energy savings in comparison to the WSEC while the LEED program savings vary widely. It should be noted that the Built Green modeling standards are not well defined, so whether or not the savings are actually achieved will depend on the quality of the modeling.

The ASHRAE 90.1 base case buildings are significantly less energy efficient than the WSEC base case building. This places the bar very low for the LEED program. In the case of the gas heated high rise, without any additional measures the WSEC base case building is about 12% more efficient than the ASHRAE base case. This means that to meet the energy savings prerequisite for the LEED program the building only needs to implement measures saving 2% over the WSEC base case. This can be achieved simply by adding 1.75GPM showerheads. Obviously, this is not a high enough bar for this type of building. There are no other energy requirements in the program to achieve a Gold rating. However, we assumed that a building attempting a Gold certification level would likely achieve additional energy points as long as they could be achieved relatively easily. In the mid-rise prototypes and in the high rise electric prototype only 2 points are easily achieved. To earn more points it would be necessary to install triple glazing or some type of air or water heat recovery system, or heat pump heating in the case of the electric prototypes. Therefore only 2-points could be reliably expected for Silver or Gold buildings for these prototypes. In the case of the high rise gas heated building it is easier to achieve 4 points so it was assumed that the Gold level building would employ those necessary measures.

The measures used and the associated savings for each cumulative measure are shown in the tables and figures below.

Table 5. Measures and Savings for Mid and High-Rise Multifamily Buildings

Measure Description	%Savings Over WSEC	% Savings Over ASHRAE[27]	Certification Level / Points
Mid-Rise Gas-Heated LEED Prototype			
---		0.0%	ASHRAE 90.1
Envelope Improvements to WSEC		4.5%	2006 WSEC
South Overhangs		7.1%	
Low Flow Plumbing Fixtures 77% water use		11.1%	1 Point
92% DHW/Space Combo Boiler		13.5%	
Variable Speed Pumping HW Loop		14.4%	2 Points – Silver/Gold
Mid-Rise Electric-Heated LEED Prototype			
---		0.0%	ASHRAE 90.1
Envelope Improvements to WSEC		2.9%	2006 WSEC
South Overhangs		5.1%	
Low Flow plumbing 77% water use		11.2%	1 Point
Better Double Pane Glass 0.40/0.36 > 0.32/0.34 (U/SHGC)		13.3%	
Triple Pane Glass 0.32/0.34 > 0.23/0.25 (U/SHGC)		15.7%	2 Points – Silver/Gold
Mid-Rise Gas-Heated Built Green Prototype			
---	0.0%	[28]	2006 WSEC
1KW Solar PV (1150kwh/70 units)	0.2%		Prerequisite
Low Flow Plumbing 77%	6.1%		
Lighting (1.75>1.0W/ft^2)	9.3%		
Lighting (1.0>0.6W/ft^2)	10.8%		
Energy Star Appliances (1800>1500kwh/yr/unit)	11.7%		
92% DHW/Space Combo Boiler	16.5%		4-Star
Variable Speed Pumping HW Loop	19.9%		
Better Double Pane Glass 0.40/0.36 > 0.32/0.34 (U/SHGC)	23.3%		
Triple Pane Glass 0.32/0.34 > 0.23/0.25 (U/SHGC)	25.6%		
Corridor HX (65% recovery efficiency)	31.9%		5-Star
Mid-Rise Electric-Heated Built Green Prototype			
---	0.0%		2006 WSEC
1KW Solar PV (1150kwh/70 units)	0.2%		Prerequisite
Low Flow Plumbing 77%	6.0%		
Lighting (1.0>0.6W/ft^2)	11.8%		
Energy Star Appliances (1800>1500kwh/yr/unit)	13.0%		
Better Double Pane Glass 0.40/0.36 > 0.32/0.34 (U/SHGC)	16.2%		4-Star
Triple Pane Glass 0.32/0.34 > 0.23/0.25 (U/SHGC)	21.8%		
Wastewater HX	24.9%		
Corridor HX (65% recovery efficiency)	31.9%		5-Star

[27] Note that LEED modeling compared to an ASHRAE base case requires the inclusion of modeled cooling energy even if no cooling equipment is present.
[28] An ASHRAE base case was not modeled for the Built Green program analysis.

High-Rise Gas-Heated LEED			
---		0.0%	ASHRAE 90.1
Envelope Improvements to WSEC		12.0%	2006 WSEC
Low Flow Showers 83% water use (1.75gpm shower)		14.5%	2 Points - Silver
Low Flow Lavs and K-sinks		15.4%	
92% DHW Boiler		17.0%	3 Points
92% Space Heating Boiler		18.5%	
Glass 0.40/0.36 > 0.36/0.32 (U/SHGC)		20.4%	
Chiller COP from 2.8>3.1		21.2%	4 Points - Gold
High-Rise Electric-Heated LEED Prototype			
---		0.0%	ASHRAE 90.1
Envelope Improvements to WSEC		8.8%	2006 WSEC
Low Flow plumbing 77% water use		13.6%	
Chiller COP from 2.8>3.1		14.7%	2 Points – Silver/Gold
High-Rise Gas-Heated Built Green Prototype			
---	0.0%		2006 WSEC
1KW Solar PV (1150kwh/190 units)	0.0%		Prerequisite
Low Flow Plumbing 77%	5.0%		
Lighting (1.75>0.6W/ft^2)	12.7%		
Energy Star Appliances (1800>1500kwh/yr/unit)	13.7%		
DHW Boiler 80%>92%	16.1%		
Space Heating Boiler 80%>92%	19.6%		4-Star
High Eff Airside Centrifugal Chiller (COP 3.1)	21.7%		
Glass 0.40/0.36 > 0.36/0.32 (U/SHGC)	23.7%		
WastewaterHX	26.0%		
Corridor HX (65% recovery efficiency)	30.2%		5-Star
High-Rise Electric-Heated Built Green Prototype			
---	0.0%		2006 WSEC
1KW Solar PV (1150kwh/190 units)	0.0%		Prerequisite
Low Flow Plumbing 77%	5.4%		
Lighting (1.75>0.6W/ft^2)	11.0%		
Energy Star Appliances (1800>1500kwh/yr/unit)	11.8%		
High Eff Airside Centrifugal Chiller (COP 3.1)	12.7%		
Wastewater HX	15.1%		4-Star
Corridor HX (65% recovery efficiency)	22.2%		
Glass 0.40/0.36 > 0.36/0.32 (U/SHGC)	24.2%		
Triple Glass (0.25/.28)	28.6%		
Quad Glass (0.16/0.25)	32.2%		5-Star

Figure 11. Annual Site Energy Use, Mid Rise, 887 ft^2 Unit

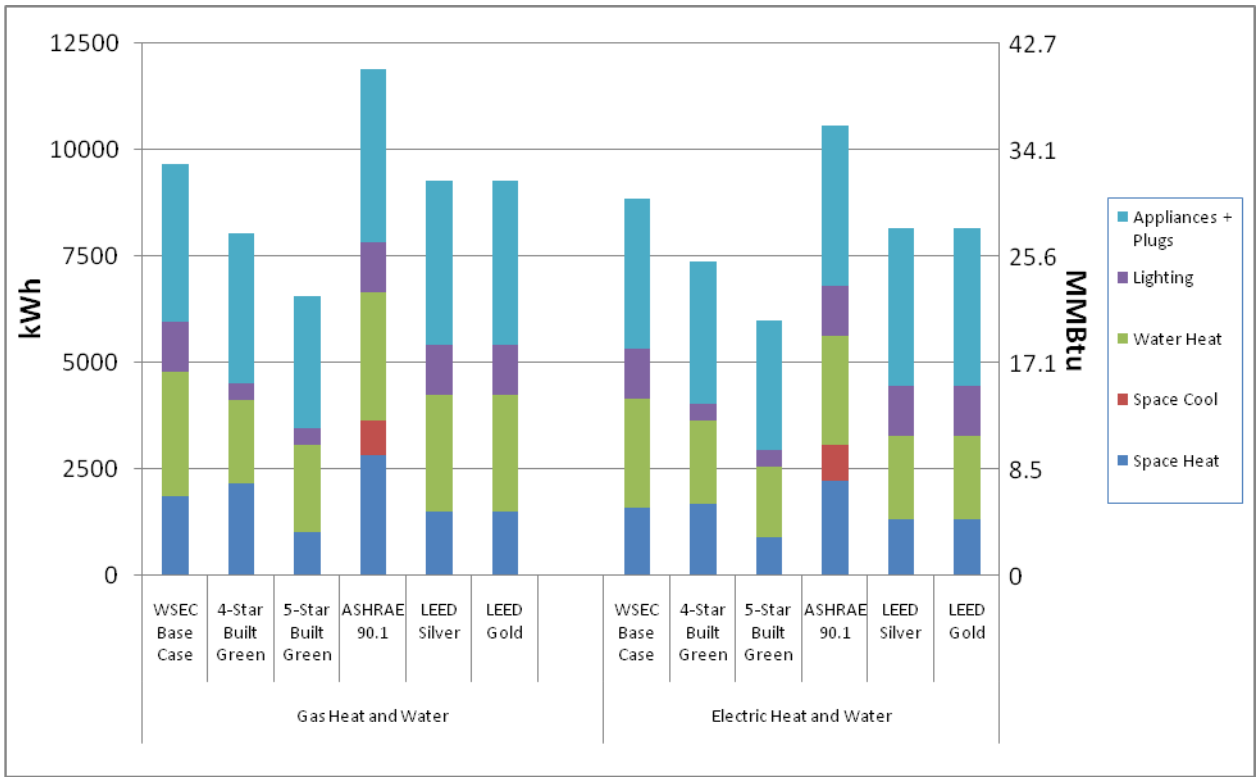


Figure 12. Source Energy CO_2 Emissions, Mid Rise, 887 ft^2 Unit

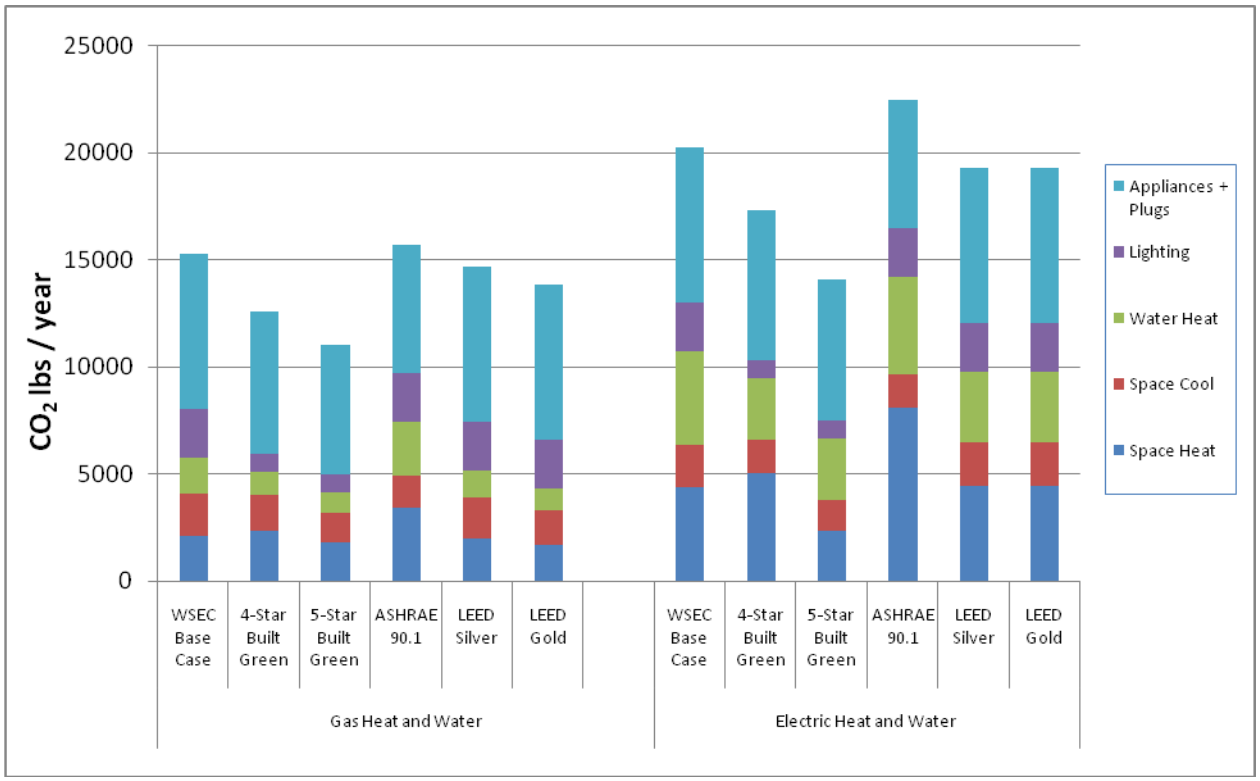


Figure 13. Annual Site Energy Use, High Rise, 1,232 ft^2 Unit

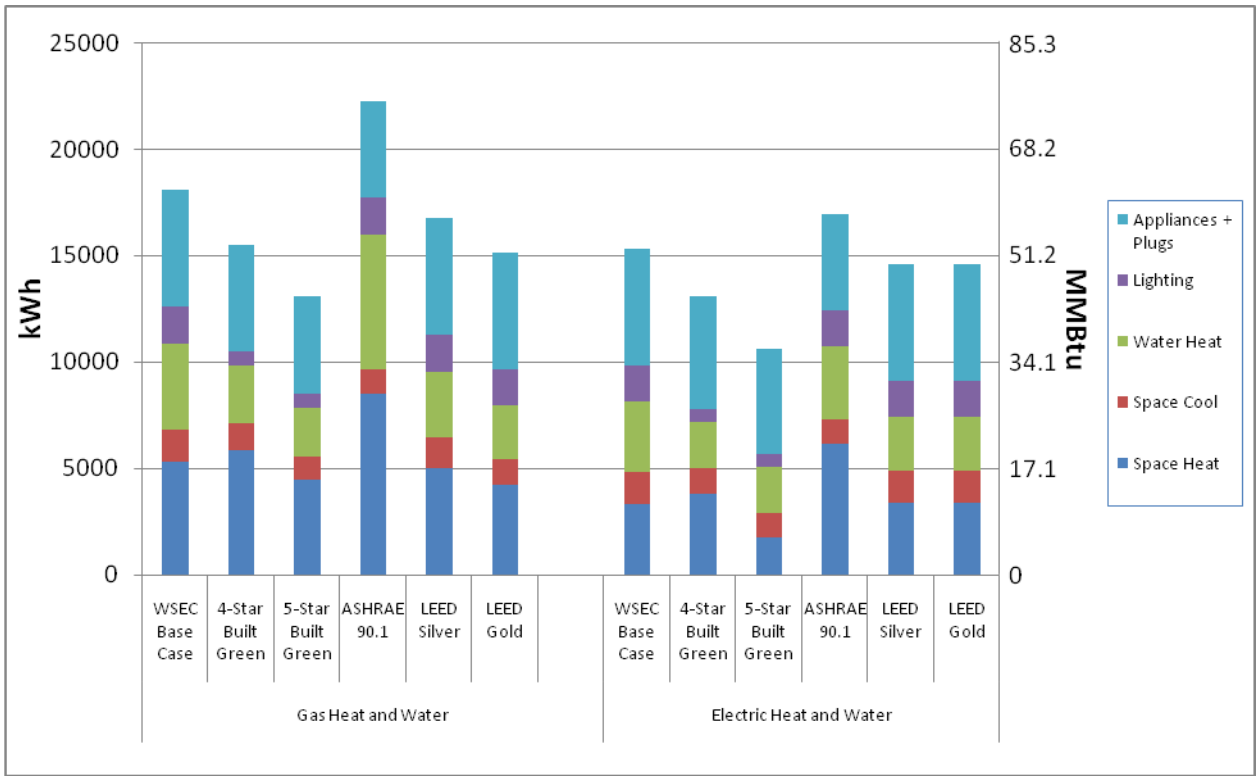
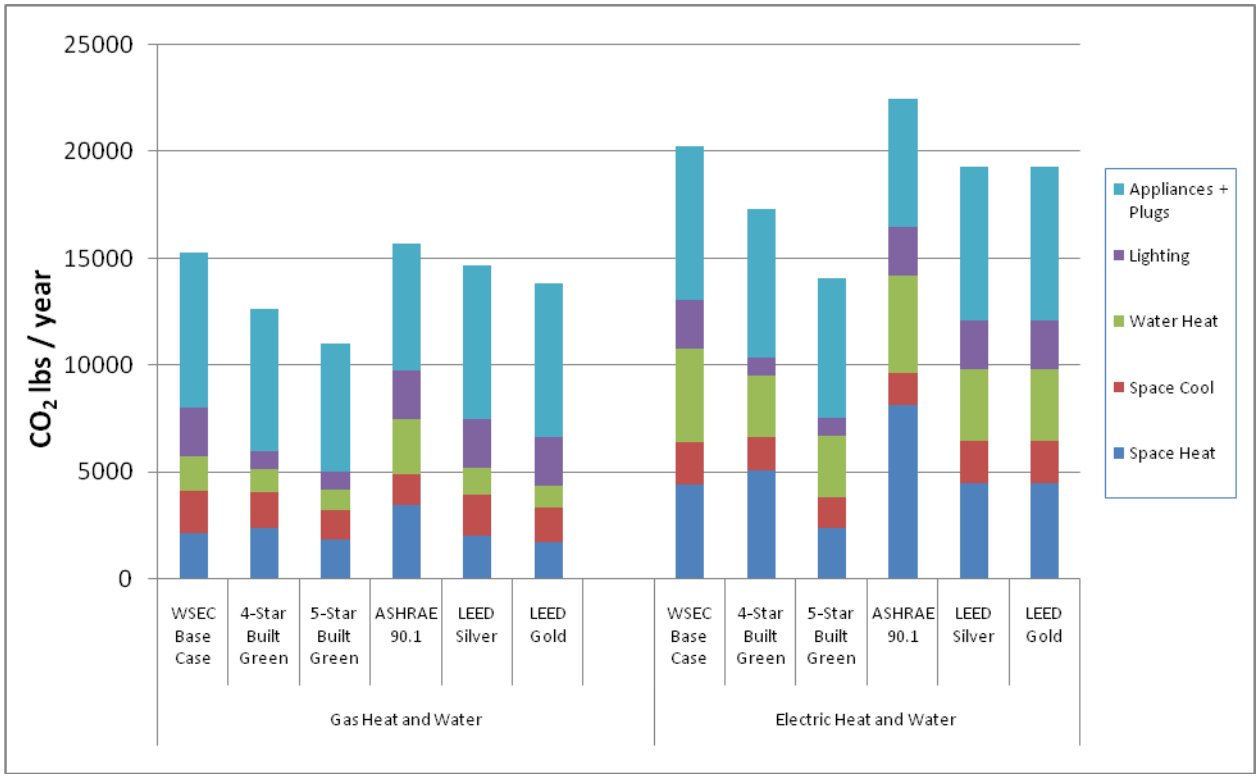


Figure 14. Source Energy CO_2 Emissions, High Rise, 1,232 ft^2 Unit



Since these programs are not based on prescriptive measures, the measures applied and the order that they were applied were based on our own experience working with developers in this region and designing these buildings. In the case of the Built Green program measures were added one at a time until the 15% or 30% thresholds were met. In the case of the LEED program measures were added until the 2-point minimum was attained and then any additional easy or inexpensive measures were added in the case of the Gold buildings. We chose the measures that we thought would be easiest and cheapest first, and measures which would have the largest impact on annual energy use. These packages of measures are not guaranteed to be the actual measures that would appear in any given building. Rather they are implemented to demonstrate that the various levels of conservation are achievable and to provide an example of how they might be achieved. Note that many more conservation measures had to be applied to achieve the Built Green certification levels than for the LEED certifications. For the 5-Star Built Green Buildings we needed to implement measures which are rarely adopted in multifamily buildings in this region (but all of them have been applied in some buildings that we have been involved with). This included measures such as heat recovery from the waste water and the ventilation air and triple and quad glazing. It was assumed that since the LEED program does not require these measures that most LEED buildings would only implement the easy measures after achieving the mandatory 2 points.

It is clear from this analysis that the Built Green program sets a bar which is achievable but a reach for most multifamily developers, while the LEED program does not guarantee any particular level of regional energy savings.

Glazing Analysis

In addition to home size, another variable that can have a large impact on energy use in residential buildings is the amount of glazing installed. The following graph displays the results of a parametric analysis examining the effect of glazing area on total energy use in single family homes. The purpose of the study was to specifically investigate if the gains made by following a Built Green or LEED path are offset by uncontrolled window area. Four window areas were considered: 15%, 21%, 25%, and 35% of conditioned floor area. The windows are assumed to be equally distributed around the building faces. For reference, the detailed results presented in the preceding single family sections are for a 21% glazed building.

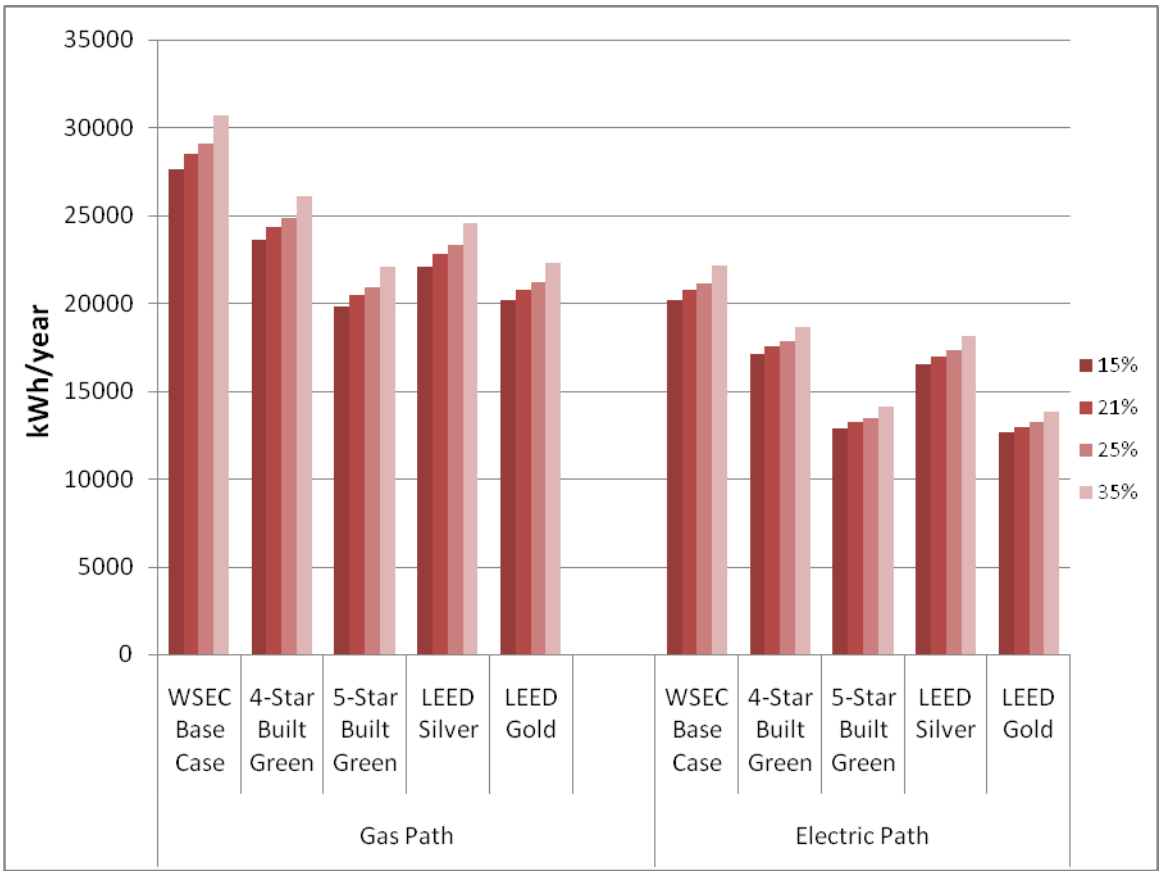
The graph shows about a 10-12% increase in total building energy use associated with the increase in glazing fraction. This relates to about a 20-25% increase in the heating energy. It should be noted that the LEED and Built Green programs nominally require the buildings to comply with the Energy Star program. Northwest Energy Star prescriptive standards limit the glazing area to no more than 21%. We highly recommend that this limit be maintained and enforced as it puts a cap on the heat loss rate and thus limits the heating energy required.

Energy use in the multifamily prototypes is also sensitive to both glazing area and building orientation. While glazing fraction in the single family programs is effectively limited to 21% by the EnergyStar program, there is no similar limit in the multifamily programs. The WSEC provides an unlimited glazing option as a prescriptive path and the trend in "Green Buildings" has been to emphasize daylighting and views over energy efficiency with large expanses of glazing (frequently floor-to-ceiling). This has been inadvertently encouraged by the LEED program since the baseline window performance is a U-Value of 0.62 while the WSEC maximum value is 0.35. This has the effect of assigning a large energy savings for heavily glazed buildings simply for meeting the code requirement.

Note also that in buildings with installed cooling high levels of glazing increase both the heating and cooling energy required. The LEED modeling criteria requires modeling of cooling whether or not cooling is installed. This gives further credit to highly glazed buildings. For example South overhangs are a measure in the LEED rating system because of the cooling load reduction. The south overhang measure is not listed in the Built Green multifamily cases because cooling is not required to be modeled and this measure results in a slight increase in heating energy. Overhangs in our region are typically used as cooling control measures where cooling systems are not installed.

Some method to limit glazing percentage in multifamily buildings should be considered by future Green Building programs in the region.

Figure 15. Impact of Varying Glazing Level on Total Energy Use of 1,850 ft^2 Prototype



Appendix A: SEEM Hourly Output Sample

SEEM Hourly Output Sample

SEEM Simulation Model v.0.914 Date: 08/22/2008 Time: 15:25:08 Run: sbaseFURg15 File: ose_one.csv

TMY2 Header: 727930 SEATTLE SEATTLE-TACOMA WA -8 N 47 28 W 122 19 122

HOUSE		FOUNDATION		WINDOWS		SUPPLY DUCTS		RETURN DUCTS		HEAT EQUIPMENT		COOL EQUIPMENT	
Flr Area:	1850	Ftprnt Area:	805	WinArea:	277.5	Location:	CRAWL	Location:	CRAWL	Theat:	70 64	Tcool:	200 200
UA:	373.5	Perimeter:	121	SwinArea:	69.4	Area:	250	Area:	80	Type:	Elec Furn	Type:	NONE
Qgains:	2554	Type:	Crawl	SHGC:	.380	Leak Frac:	.12	Leak Frac:	.10	Size:	10.00 kw	Size:	.00 Tons
Wgains:	1.00	UA Bgrade:	120.1	Uvalue:	.350	Rvalue:	6.00	Rvalue:	6.00	CFM:	710	CFM:	710
HouseACH:	.35	UA Agrade:	285.8	Shading:	.54	ZoneACH:	4.50	ZoneACH:	4.50	SCFM:	702	SCFM:	702
Volume:	15725	Crawl Vol:	2817			ZoneCFM:	211	ZoneCFM:	211	HPControl:	0	TControl:	30.0

Heating Design Day Feb 19

Hr	Cld	Qhor Btuh	Qver Btuh	Qsky Btuh	Tdew F	Tsky F	Tout F	Trf F	Tat F	Tcl F	Tew F	Tiw F	Tfl F	Tcr F	Tgr F	Trad F	Tair F	Room kBtuh	Equip kBtuh	Input kBtuh	Aux kBtuh	RHhs %	RHat %	RHcr %	RHou %
1	0	0	0	-29	21	-18	25	22	24	63	62	64	65	41	44	63.7	64.0	5.3	6.9	6.9	.0	37	88	45	85
2	0	0	0	-29	21	-19	24	19	22	63	62	64	64	41	44	63.2	64.0	8.2	10.6	10.6	.0	36	96	45	88
3	0	0	0	-30	21	-17	26	19	22	62	62	63	63	42	43	62.9	64.0	9.5	12.4	12.4	.0	36	97	44	81
4	0	0	0	-29	21	-21	23	19	21	62	61	63	63	41	43	62.7	64.0	11.0	14.3	14.3	.0	36	100	46	92
5	0	0	0	-30	19	-23	22	17	19	62	61	63	62	41	43	62.6	64.0	12.0	15.7	15.7	.0	35	98	43	88
6	0	0	0	-30	18	-24	22	16	19	62	61	63	62	49	43	63.6	70.0	41.8	53.3	53.3	19.2	26	97	35	85
7	3	0	0	-27	19	-16	23	16	19	66	64	66	63	47	44	66.0	70.0	27.2	36.1	36.1	2.0	24	100	37	85
8	2	10	18	-28	18	-19	23	18	20	66	65	67	64	46	44	66.8	70.0	22.5	30.1	30.1	.0	24	90	36	81
9	1	46	67	-31	20	-19	26	22	24	67	66	68	65	46	44	67.6	70.0	18.6	24.8	24.8	.0	25	82	38	78
10	1	92	92	-31	19	-17	28	32	32	67	66	68	66	45	44	68.4	70.0	14.8	19.6	19.6	.0	27	55	38	69
11	2	133	102	-31	18	-15	29	42	40	68	67	69	66	44	44	68.8	70.0	12.0	15.9	15.9	.0	27	38	36	64
12	2	132	83	-31	20	-11	32	50	46	68	67	69	67	45	44	69.1	70.0	10.1	13.2	13.2	.0	28	32	38	61
13	2	146	80	-31	18	-7	35	55	51	69	68	69	67	45	44	69.2	70.0	8.9	11.7	11.7	.0	28	25	35	50
14	3	130	84	-30	17	-4	36	58	54	69	68	69	68	45	44	69.4	70.0	7.9	10.4	10.4	.0	27	21	33	46
15	3	111	86	-30	15	-4	36	57	53	69	68	70	68	45	44	69.5	70.0	7.2	9.5	9.5	.0	26	20	30	42
16	2	81	81	-30	16	-3	37	53	50	69	68	70	68	45	44	69.6	70.0	6.7	8.7	8.7	.0	26	23	31	42
17	3	32	40	-28	18	-2	35	46	44	69	68	70	68	44	44	69.4	70.0	7.2	9.5	9.5	.0	27	32	34	50
18	2	6	9	-29	19	-8	32	36	36	69	68	69	68	44	44	69.0	70.0	9.2	12.1	12.1	.0	28	46	37	59
19	0	0	0	-32	19	-16	30	29	30	68	67	69	68	44	44	68.7	70.0	11.1	14.7	14.7	.0	28	59	38	64
20	2	0	0	-29	18	-11	30	25	27	68	67	69	68	45	44	68.5	70.0	12.2	16.1	16.1	.0	27	64	36	61
21	2	0	0	-29	18	-12	29	24	26	68	67	69	68	45	44	68.4	70.0	12.8	17.0	17.0	.0	27	67	36	64
22	2	0	0	-28	19	-11	29	23	26	68	67	69	67	40	44	67.8	67.3	.0	.0	.0	.0	32	73	39	66
23	2	0	0	-29	17	-11	30	23	26	66	65	67	67	40	44	65.9	65.4	.0	.0	.0	.0	32	65	35	58
24	2	0	0	-28	18	-11	29	23	26	64	63	65	66	40	43	64.5	64.0	.1	.1	.1	.0	35	69	38	64

Annual Summary: Press: .9882 (atm), Tout: 52.23, Tsky: 34.75, Qsky: -14.99, Qhor: 44.86, Qvert: 25.30
Annual Summary: Latent Pct: .0, Wout: 6.270, Whse: 8.674, Watt: 6.261, Wcrl: 6.344, Run time (sec): 2.063

	Room	Equip	Input	Latent	Aux	Fan
Annual Heating Energy Loads (kWh):	8727	11159	11159	0	163	312
Annual Cooling Energy Loads (kWh):	0	0	0	0	0	0
Maximum Heating Loads (Btu/h):	41772	53322	53322	0	19202	970
Maximum Cooling Loads (Btu/h):	0	0	0	0	0	970

Appendix B: Single Family Model Results

Single Family, 1850 ft^2

	Base Case	4-Star Built Green	5-Star Built Green	LEED Silver	LEED Gold		Base Case	4-Star Built Green	5-Star Built Green	LEED Silver	LEED Gold
	Gas Heat and Water						Electric Heat and Water				
Annual Energy Use (kWh)											
Space Heat	14839	12683	10572	12026	11771		9293	7830	3401	7830	3966
Space Cool									500		458
Water Heat	6197	5440	4080	4552	3176		3993	3510	3510	2937	2732
Lighting	2363	1486	1080	1486	1080		2363	1486	1080	1486	1080
Appliances + Plugs	5075	4720	4720	4720	4720		5075	4720	4720	4720	4720
Total	**28474**	**24329**	**20453**	**22784**	**20747**		**20725**	**17545**	**13212**	**16972**	**12956**
kWh savings vs base	0	4145	8021	5690	7726		0	3180	7513	3753	7769
% savings vs base	0%	15%	28%	20%	27%		0%	15%	36%	18%	37%
Annual CO2 Emissions (lbs)											
Space Heat	5924	5063	4220	4801	4699		12293	10357	4498	10357	5246
Space Cool									662		605
Water Heat	2474	2172	1629	1817	1268		5282	4643	4643	3885	3614
Lighting	3126	1965	1429	1965	1429		3126	1965	1429	1965	1429
Appliances + Plugs	6713	6243	6243	6243	6243		6713	6243	6243	6243	6243
Total	**18237**	**15443**	**13522**	**14827**	**13640**		**27414**	**23208**	**17476**	**22450**	**17138**
lbs savings vs base	0	2793	4715	3410	4597		0	4206	9938	4964	10276
% savings vs base	0%	15%	26%	19%	25%		0%	15%	36%	18%	37%
Annual Energy Costs ($)											
Space Heat	582	498	415	472	462		697	587	255	587	297
Space Cool									38		34
Water Heat	243	213	160	179	125		299	263	263	220	205
Lighting	177	111	81	111	81		177	111	81	111	81
Appliances + Plugs	381	354	354	354	354		381	354	354	354	354
Total	**1383**	**1177**	**1010**	**1116**	**1022**		**1554**	**1316**	**991**	**1273**	**972**

Single Family, 2800 ft^2

	Base Case	4-Star Built Green	5-Star Built Green	LEED Silver	LEED Gold		Base Case	4-Star Built Green	5-Star Built Green	LEED Silver	LEED Gold
	Gas Heat and Water						Electric Heat and Water				
Annual Energy Use											
Space Heat	25075	21299	18482	20268	19875		15711	13347	6104	13347	7022
Space Cool									538		503
Water Heat	6197	5440	4080	4552	3176		3993	3510	3510	2937	2732
Lighting	3577	2248	1635	2248	1635		3577	2248	1635	2248	1635
Appliances + Plugs	5075	4720	4720	4720	4720		5075	4720	4720	4720	4720
Total	**39924**	**33708**	**28917**	**31788**	**29406**		**28357**	**23825**	**16508**	**23252**	**16613**
kWh savings vs base	0	6216	11006	8135	10518		0	4531	11849	5104	11744
% savings vs base	0%	16%	28%	20%	26%		0%	16%	42%	18%	41%
Annual CO2 Emissions (lbs)											
Space Heat	10010	8503	7378	8091	7934		20783	17655	8075	17655	9289
Space Cool	0	0	0	0	0		0	0	712	0	666
Water Heat	2474	2172	1629	1817	1268		5282	4643	4643	3885	3614
Lighting	4732	2974	2163	2974	2163		4732	2974	2163	2974	2163
Appliances + Plugs	6713	6243	6243	6243	6243		6713	6243	6243	6243	6243
Total	**23928**	**19892**	**17413**	**19126**	**17609**		**37509**	**31515**	**21836**	**30758**	**21975**
lbs savings over base	0	4036	6515	4803	6320		0	5994	15674	6752	15534
% savings over base	0%	17%	27%	20%	26%		0%	16%	42%	18%	41%
Annual Energy Costs ($)											
Space Heat	984	836	725	795	780		1178	1001	458	1001	527
Space Cool	0	0	0	0	0		0	0	40	0	38
Water Heat	243	213	160	179	125		299	263	263	220	205
Lighting	268	169	123	169	123		268	169	123	169	123
Appliances + Plugs	381	354	354	354	354		381	354	354	354	354
Total	**1876**	**1572**	**1362**	**1497**	**1381**		**2127**	**1787**	**1238**	**1744**	**1246**

Town Home, 1400 ft^2

	Base Case	4-Star Built Green	5-Star Built Green	LEED Silver	LEED Gold		Base Case	4-Star Built Green	5-Star Built Green	LEED Silver	LEED Gold
	Gas Heat and Water						Electric Heat and Water				
Annual Energy Use											
Space Heat	7370	6407	5168	5951	5810		4716	3646	1431	3646	1931
Space Cool									569		519
Water Heat	5320	4671	3503	3908	2727		3428	3013	3013	2521	2346
Lighting	1789	1124	818	1124	818		1789	1124	818	1124	818
Appliances + Plugs	5075	4720	4720	4720	4720		5075	4720	4720	4720	4720
Total	**19553**	**16922**	**14208**	**15703**	**14075**		**15007**	**12504**	**10551**	**12012**	**10333**
kWh savings vs base	0	2631	5344	3849	5478		0	2504	4457	2996	4675
% savings vs base	0%	13%	27%	20%	28%		0%	17%	30%	20%	31%
Annual CO2 Emissions (lbs)											
Space Heat	2942	2558	2063	2376	2320		6238	4823	1893	4823	2554
Space Cool	0	0	0	0	0		0	0	753	0	686
Water Heat	2124	1865	1398	1560	1089		4535	3986	3986	3335	3103
Lighting	2366	1487	1081	1487	1081		2366	1487	1081	1487	1081
Appliances + Plugs	6713	6243	6243	6243	6243		6713	6243	6243	6243	6243
Total	**14144**	**12153**	**10786**	**11666**	**10733**		**19851**	**16539**	**13956**	**15889**	**13668**
lbs savings vs base	0	1992	3358	2478	3411		0	3312	5895	3963	6184
% savings vs base	0%	14%	24%	18%	24%		0%	17%	30%	20%	31%
Annual Energy Costs ($)											
Space Heat	289	251	203	233	228		354	273	107	273	145
Space Cool	0	0	0	0	0		0	0	43	0	39
Water Heat	209	183	137	153	107		257	226	226	189	176
Lighting	134	84	61	84	61		134	84	61	84	61
Appliances + Plugs	381	354	354	354	354		381	354	354	354	354
Total	**1013**	**873**	**756**	**825**	**750**		**1126**	**938**	**791**	**901**	**775**

Appendix C: Multifamily Model Results

High Rise, 1232 ft^2

	WSEC Base Case	4-Star Built Green	5-Star Built Green	ASH-RAE 90.1	LEED Silver	LEED Gold		WSEC Base Case	4-Star Built Green	5-Star Built Green	ASH-RAE 90.1	LEED Silver	LEED Gold
	Gas Heat and Water							**Electric Heat and Water**					
Annual Energy Use (kWh)													
Space Heat	5299	5866	4471	8538	5006	4205		3299	3798	1755	6133	3363	3363
Space Cool	1500	1276	1063	1121	1446	1230		1506	1203	1115	1155	1511	1511
Water Heat	4095	2750	2365	6367	3399	2750		3326	2202	2202	3455	2561	2561
Lighting	1724	642	642	1724	1724	1724		1724	642	642	1724	1724	1724
Appliances + Plugs	5480	5024	4572	4528	5476	5462		5456	5287	4962	4528	5479	5479
Total	**18098**	**15557**	**13113**	**22277**	**17051**	**15371**		**15312**	**13132**	**10676**	**16995**	**14638**	**14638**
kWh savings vs WSEC	0	2541	4985	-4179	1048	2727		0	2180	4635	-1683	674	674
% savings vs WSEC	0%	14%	28%	-23%	6%	15%		0%	14%	30%	-11%	4%	4%
Annual CO2 Emissions (lbs)													
Space Heat	2115	2342	1785	3408	1998	1679		4364	5024	2322	8112	4448	4448
Space Cool	1984	1688	1406	1482	1912	1627		1993	1592	1475	1528	1999	1999
Water Heat	1635	1098	944	2542	1357	1098		4399	2913	2913	4570	3387	3387
Lighting	2281	849	849	2281	2281	2281		2281	849	849	2281	2281	2281
Appliances + Plugs	7249	6645	6048	5989	7243	7225		7217	6993	6563	5989	7247	7247
Total	**15264**	**12621**	**11032**	**15702**	**14792**	**13909**		**20254**	**17370**	**14122**	**22480**	**19362**	**19362**
Annual Energy Costs ($)													
Space Heat	208	230	175	335	196	165		247	285	132	460	252	252
Space Cool	113	96	80	84	108	92		113	90	84	87	113	113
Water Heat	161	108	93	250	133	108		249	165	165	259	192	192
Lighting	129	48	48	129	129	129		129	48	48	129	129	129
Appliances + Plugs	411	377	343	340	411	410		409	396	372	340	411	411
Total	**1021**	**859**	**739**	**1138**	**978**	**904**		**1148**	**985**	**801**	**1275**	**1098**	**1098**

Mid Rise Flats, 887 ft^2

	WSEC Base Case	4-Star Built Green	5-Star Built Green	ASH-RAE 90.1	LEED Silver	LEED Gold		WSEC Base Case	4-Star Built Green	5-Star Built Green	ASH-RAE 90.1	LEED Silver	LEED Gold
	Gas Heat and Water							**Electric Heat and Water**					
Annual Energy Use (kWh)													
Space Heat	1865	2171	1036	2821	1516	1516		1593	1701	893	2231	1333	1333
Space Cool				837							837		
Water Heat	2937	1982	2056	2985	2098	2098		2550	1963	1689	2550	1963	1963
Lighting	1175	403	403	1175	1175	1175		1175	403	403	1175	1175	1175
Appliances + Plugs	3693	3524	3098	4067	3848	3848		3523	3339	3036	3791	3729	3729
Total	**9670**	**8081**	**6593**	**11886**	**8637**	**8637**		**8841**	**7406**	**6021**	**10584**	**8200**	**8200**
kWh savings vs WSEC	0	1590	3077	-2216	1033	1033		0	1435	2820	-1743	641	641
% savings vs WSEC	0%	16%	32%	-23%	11%	11%		0%	16%	32%	-20%	7%	7%
Annual CO2 Emissions (lbs)													
Space Heat	745	867	414	1126	605	605		2108	2250	1182	2951	1763	1763
Space Cool				1108							1108		
Water Heat	1172	791	821	1192	838	838		3373	2597	2234	3373	2597	2597
Lighting	1554	533	533	1554	1554	1554		1554	533	533	1554	1554	1554
Appliances + Plugs	4886	4662	4098	5380	5090	5090		4660	4417	4016	5014	4933	4933
Total	**8357**	**6853**	**5865**	**10360**	**8087**	**8087**		**11695**	**9797**	**7965**	**14000**	**10847**	**10847**
Annual Energy Costs ($)													
Space Heat	73	85	41	111	59	59		119	128	67	167	100	100
Space Cool											63		
Water Heat	115	78	81	117	82	82		191	147	127	191	147	147
Lighting	88	30	30	88	88	88		88	30	30	88	88	88
Appliances + Plugs	277	264	232	305	289	289		264	250	228	284	280	280
Total	**554**	**458**	**384**	**621**	**519**	**519**		**663**	**555**	**452**	**794**	**615**	**615**